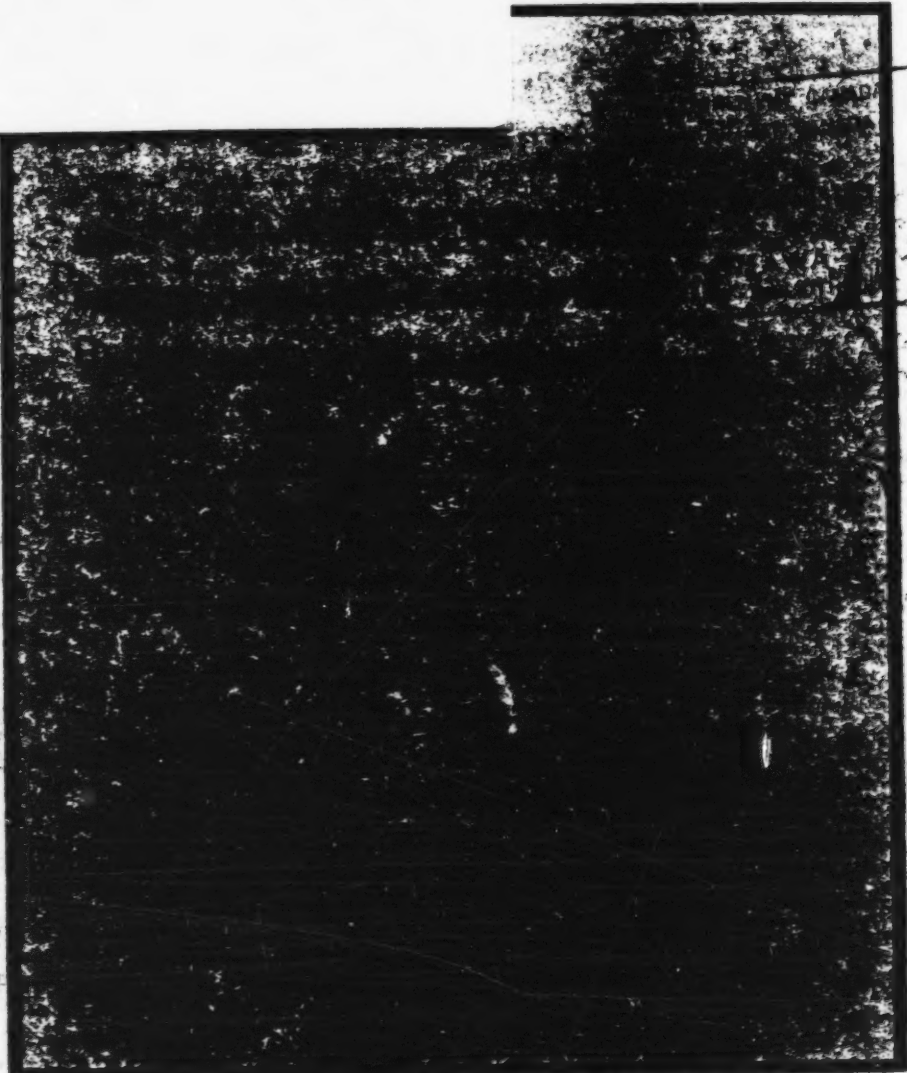


692



FISHERIES AND MARINE SERVICE
SERVICE DES PÊCHES ET DES SCIENCES DE LA MER

TECHNICAL REPORT No. 692
RAPPORT TECHNIQUE N° 692

1977



no. 692
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Department of the Environment
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Research and Development Directorate

TECHNICAL REPORT NO. 692

(Numbers 1-456 in this series were issued
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Ministère de l'Environnement
Service des Pêches et des Sciences de la mer
Direction de la Recherche et Développement

RAPPORT TECHNIQUE N^o. 692

(Les numéros 1-456 dans cette série furent
utilisés comme Rapports Techniques de l'Office
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Le nom de la série fut changé avec le
rapport numéro 457)

Lake Huron, 1974: PCB, chlorinated insecticides,
heavy metals and radioactivity in offshore fish

by

F.A.J. Armstrong and A. Lutz

This is the ninety eighth
Technical Report from the
Research and Development Directorate
Freshwater Institute
Winnipeg, Manitoba

Ceci est le quatre-vingt dix-huitième
Rapport Technique de la Direction de la
Recherche et Développement
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Winnipeg, Manitoba

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ACKNOWLEDGEMENTS

O.E. Acres provided the measurements of radioactivity, W.J. Taylor the SSMS analyses and G.E. Glass the identifications of organic contaminants. We are grateful to R.V. Hunt, K.C. Tam, N. Grift and B. Thomson for analytical assistance and to A.W. Rieger for confirming identification of pesticides. Adele Yakimischak made the statistical computations; typing was done by Grace Decterow and Carol Catt.

ABSTRACT

ARMSTRONG, F.A.J. and A. LUTZ. 1977. Lake Huron 1974: PCB, chlorinated insecticides, heavy metals and radioactivity in offshore fish. Fish. Mar. Serv. Tech. Rep. 692: v + 14 p.

Thirteen samples of burbot (*Lota lota*), bloater chub (*Coregonus hoyi*), and slimy sculpin (*Cottus cognatus*), comprising 569 fish from 6 locations in Lake Huron in 1974 were analysed for contaminants. Most samples were of about 50 whole fish; these were grouped in fives to make 10 subsamples which were homogenised for analysis.

PCB, dieldrin, DDT fractions and mercury were determined on all 13 samples, and BHC, methoxychlor, chlordane, As, Cd, Cr, Cu, Pb, Se and Zn on 5. Some samples were also tested for other organics, for other metals and for radioactivity. The methods used are given in outline, with their reproducibility. Mean length, weight, and fat content are listed.

PCB was above the present Canadian limit of 2 µg/g in one sample of bloater chub and in one of burbot. All samples comply with Canadian and U.S. regulations for DDT and mercury. There were few consistent species differences in levels of chlorinated insecticides. Two samples of bloater chub contained arsenic at 1.72 and 2.26 µg/g. Radioactivity was low.

Key Words: Lake Huron, PCB, chlorinated pesticides, metals, radioactivity.

RÉSUMÉ

ARMSTRONG, F.A.J. and A. LUTZ. 1977. Lake Huron 1974: PCB, chlorinated insecticides, heavy metals and radioactivity in offshore fish. Fish. Mar. Serv. Tech. Rep. 692: v + 14 p.

En vue d'examiner les agents de contamination, on a analysé en 1974 13 échantillons de lottes (*Lota lota*), de ciscos de fumage (*Coregonus hoyi*), et de chabots visqueux (*Cottus cognatus*) comprenant 569 poissons provenant de 6 endroits du Lake Huron. La plupart des échantillons comprenaient environ 50 poissons entiers; on a groupé ces derniers cinq par cinq pour former 10 sous-échantillons qui furent homogénéisés pour l'analyse.

On a trouvé du PCB, de la dieldrine, des éléments de DDT et du mercure dans les 13 échantillons, ainsi que du BHC, du méthoxychlore, du chlordane, As, Cd, Cr, Cu, Pb, Se et Zu dans 5 échantillons. On a également examiné certains échantillons pour y chercher d'autres substances organiques, d'autres métaux et de la radioactivité. On donne les grandes lignes des méthodes dont on s'est servi ainsi que leur reproductibilité. On énumère la longueur moyenne, le poids et la teneur en graisse.

Dans un échantillon de cisco de fumage et dans un échantillon de lotte, le PCB était supérieur à la limite de 2 µg par g actuellement autorisée au Canada. Tous les échantillons respectaient les normes du Canada et des États-Unis en ce qui concerne les DDT et le mercure. On a observé peu de différences entre les espèces dans les niveaux d'insecticides chlorés. Deux échantillons de ciscos de fumage contenaient respectivement 1.72 et 2.26 µg par g d'arsenic. La radioactivité était faible.

INTRODUCTION

The work reported here was commissioned and supported by the International Joint Commission on Boundary Waters. It is a part only of a study by the Upper Lakes Reference Group of the waters of Lake Huron and Lake Superior, being addressed to two of the reference questions posed to the Group, namely:

1. Are the waters of Lake Superior and Lake Huron being polluted on either side of the boundary to an extent (a) which is causing or is likely to cause injury to health or property on the other side of the boundary; or (b) which is causing or likely to cause, a degradation of existing levels of water quality in these two lakes or in downstream portions of the Great Lakes System?
2. If the foregoing questions are answered in the affirmative, to what extent, by what causes and in what localities is such pollution taking place?

It will be obvious that chemical analysis of only the offshore fish can give only partial answers to the first question, and that to answer the second requires a great deal of related information from other studies, and knowledge of water and air movements. These have been sought in other investigations and reported in publications of the Upper Lakes Reference Group. Nevertheless, we think it useful to place on record the detailed analyses which we have obtained from adequately large samples, together with outlines of the analytical methods used, and measures of the dispersion of the results. We hope that these provide reliable data for 1974 of a number of possible contaminants and will allow meaningful comparisons in the future.

Fish collections from six locations in Lake Huron (Fig. 1) were made in the fall of 1974 by Ontario Ministry of Natural Resources and by U.S. Bureau of Sport Fisheries and Wildlife. Where possible burbot (*Lota lota*), bloater chub (*Coregonus hoyi*), and slimy sculpin (*Cottus cognatus*) were taken and the intact fish frozen and shipped to the Freshwater Institute.

LABORATORY PROCEDURE AND METHODS

Sample composite and homogenization

Samples were received in the frozen state, and were then separated and identified, weighed and measured. Individual weights and lengths were recorded for most specimens, but means only were obtained for some samples of very small slimy sculpins. Fish were grouped, usually by fives, to make 10 composite samples for analysis, size and sex being disregarded. Most of the Canadian samples had already been grouped. In the tables of results the number of fish is denoted by N, the number of composite samples by n, the grouping being shown, as for example $N = 63$, $n = 10$ ($3 \times 6 + 7 \times 5$) indicating that of 10 composite samples there were three groups of 6, and seven of 5 fish.

Large fish were cut up with a bandsaw so as to go into the machine, and then homogenized by at least four passes through a Hobart grinder, by which time the tissue had partly thawed. The resultant mush was put into three separate containers, and refrozen, and kept at -20 C until analysed. The slimy sculpin samples were homogenized in a blender, by the dry-ice procedure of Benville and Tindle (1970).

Zinc and Copper

5g sample was digested with nitric and sulphuric acids, clearing with 50% hydrogen peroxide as necessary, and heated to fuming. The solution was diluted to 50 ml and zinc determined by AAS at 213.9 nm, in an air-acetylene flame with background correction.

The volume of the remaining solution was noted, the solution neutralised, buffered with acetate to pH 4.75, and copper extracted as its APDC complex into 5 ml MIBK, and determined by AAS at 324.8 nm in an air acetylene flame, with background correction.

Blanks and standards were carried through all operations.

Chromium, lead and cadmium

50g sample was partially oxidised with nitric acid, dried, ignited in Pyrex glass at 450 C, and the ash treated with nitric acid and re-ignited, repeating until a white ash was obtained. This was dissolved by heating with 2 ml concentrated nitric acid. Occasionally a small residue of sand or gravel remained from which the solution was decanted and washed and made to 50 ml. The residue was rejected. Chromium was determined by AAS at 357.9 nm in an air-acetylene flame, with background correction.

Lead and cadmium were extracted as DDDC complex into 5 ml n-butyl acetate and determined by AAS at 283.3 and 228.0 nm in an air-acetylene flame, using background correction.

Blanks and standards were carried through all stages. The direction procedures are from Analytical Methods Committee 1967 and 1973. AAS determinations were with Techtron-Varian AA5 and were conventional.

Mercury

0.5g sample was digested at 70 C with nitric and sulphuric acids, and oxidation completed with permanganate. The solution was cleared with peroxide and made to 25 ml. Mercury was determined by flameless AAS at 253.7 nm. This procedure is that of Armstrong and Uthe (1971). Blanks and standard were carried through all procedures.

Arsenic

1g sample was digested with sulphuric, nitric and perchloric acids, heated to fumes of SO₃, cooled and diluted to 25 ml. Arsenic was determined by flameless AAS at 193.7 nm by reduction to AsH₃ and decomposition in a heated tube (Vijan and Wood 1974). An electrodeless discharge lamp was used. Blanks and standard were carried through all operations.

Selenium

1g sample was digested with perchloric and sulphuric acids, using molybdate as catalyst, heated to fuming, cleared with peroxide, cooled and diluted. Selenium was determined by fluorescence of the 2,3 diaminonaphthalene complex in cyclohexane (Hoffman et al. 1968). A Turner model III fluorometer with primary filter #7-60 and secondary 2A-15/58 combination was used.

Extraction for fat and pesticides

4g sample with 6g anhydrous sodium sulphate was extracted by shaking with 20 ml hexane-acetone 1:1 for 20 min, in a stainless steel tube and heavy steel ball, and then centrifuged.

Fat

A 5 ml aliquot (representing 1g tissue) was evaporated in a current of air at room temperature, in an aluminum dish. The residue was weighed and reported as percent fat.

Clean-up

A 5 ml aliquot was taken down to 1 ml in a rotary evaporator and then to dryness under nitrogen, and redissolved in 5 ml hexane. 25 g deactivated Florisil was added and this mixture added to a column containing 25 g Florisil upon a 1 cm layer of anhydrous sodium sulphate. Pesticides and PCB were eluted with 250 ml hexane-methylene chloride (4:1), evaporated to 1 ml and then just to dryness under nitrogen, and redissolved in 5 ml acetone.

This extract was passed through a 7.5 x 0.8 cm column of Fisher Activated charcoal, and organochlorine pesticides eluted with 20 ml acetone-ether (3:1), and the eluate evaporated to dryness under nitrogen and dissolved in 5 ml hexane. This extract was washed 3x with water (previously extracted with hexane) and kept for determination of chlorinated pesticides (Langlois et al 1964).

PCB's were eluted from the charcoal column with 80 ml benzene, evaporated to dryness and dissolved in 5 ml benzene (Berg et al 1972).

Chromatography

A Micro-Tek MT 220 was used. Both pesticides and PCB were run on 6 ft column with 2% OV-1 and 4% OV 21 on 80-100 mesh Chromasorb HMDS. Injection temp 200 C, Column temperature 175C, detector tritium foil, 200 C.

All identifications were confirmed on another instrument with 6 ft column having 5% OV-210 on 80-100 mesh Chromasorb HMDS. Injection temperature 230 C Column 190 C, detector ⁶³Ni 260 C.

Spark source mass spectrometry

These analyses were performed by United States Environmental Protection Agency at the Environmental Research Laboratory under the supervision of W.J. Taylor, Analytical Chemistry Branch, who provided the following information.

The preparation deviated from the normal SSMS preparation in that 5g sample was digested in 50 ml formic acid at 60 C for 6 hours before addition of graphite. An internal spike of yttrium was added to each sample before digestion. After the digestion was completed graphite was added and the samples taken to dryness under IR lamp. The samples were then heated in a muffle furnace at 460 C for 6 hours to destroy all organic residue.

All samples were run in duplicate and the results show little or no difference among the various fish. Results for Zr, Cu, Ni and Al are not reported due to comparable values found in the formic acid blank.

Identification of organic contaminants

These analyses were performed by the U.S. Environmental Protection Agency at the Environmental Research Laboratory-Duluth under the supervision of Gary E. Glass. The results and the outline below of the procedures are from a manuscript submitted to the Upper Lakes Reference Group by Dr. Glass and made available to us.

Preparation

From the frozen homogenised samples, supplied from the Freshwater Institute, 350 g portions were blended with anhydrous sodium sulphate and extracted with hexane. The solvent was evaporated until the extract was at constant weight. A portion of the extract was dissolved in methylene chloride for gel-permeation clean-up using two 23 x 200 mm columns of Bio-Rad SX-2 polystyrene beads, methylene chloride as solvent at 4.5 ml/min and a Varian UV detector at 254 nm. Injections of 5 ml were made at 1 h intervals, 100 ml being collected 20 min after injection.

Gas chromatographic analysis

Preparations were concentrated to 2 ml in hexane, and 200 μ l transferred to 10 ml hexane for quantitative analysis. From the remainder, 2 μ l was used to obtain FID/EC traces before MS analysis. A 2 mm x 2 m OV-101 column programmed from 125 to 225°C at 4°C/min was used.

Mass spectral analysis

Preparations were concentrated to 0.2 ml, μ l being injected. The MS system was a Varian MAT CH5 (Kuehl et al 1974) being scanned from mass 50-500 every 7 sec. It was set at resolution of 1000 and operated at 70 eV.

Radioactivity

For counting approximately 5g of ash was required. This was prepared from 300g of fish which was digested with concentrated nitric acid, taken to dryness and incinerated in Pyrex glass at 450 C. The ash was treated with nitric acid and incinerated again, the treatment being repeated until a fairly white residue remained.

Counting was done in the Surveillance Section of Environmental Research WNRE of Atomic Energy of Canada Ltd. at Pinawa Manitoba, using a Beckman Wide Beta planchet counting system (gas flow) with a method based on low-environment work. The count was for either 1000 counts or 1000 minutes. Results for total beta count are expressed as ^{40}K equivalent, and are shown in Table 7. Gamma activity was measured on the whole ash sample, which was pressed to a pellet and counted with a 3" x 3" NaI crystal and a Nuclear Data 2400 multichannel analyzer. Results are reported (Table 7) as ^{137}Cs equivalent.

Reproducibility

Replicate analyses gave the results of Table 1. Samples were of fish tissue except for arsenic determination for which the U.S. Bureau of Standards Orchard leaves was used.

RESULTS AND DISCUSSION

Comparability of length and weight, by station

Burbot at three stations show large differences in size. The mean weight of the largest, from Mackinac Island is 6.5 times that of the smallest, from Georgian Bay. The ratio of the lengths was 1.8.

Bloater chub from Duck Island and Goderich were largest; those from Lonely Island smallest. The ratios of weight and length were 2.3 and 1.3.

Slimy sculpin from Georgian Bay were largest; those from Harbor Beach smallest. Weight and length ratios were 2.9 and 1.7.

Comparability of fat content, by station

There are no significant differences in fat content of the 3 burbot samples, of the 5 slimy sculpin samples, nor of 4 of the 5 bloater chub samples. These last had 20-22% fat, whereas those from Lonely Island, which were, as noted, small fish, had only 9%.

Species differences in contaminant concentrations

Where bloater chub and burbot from the same location can be compared, it is seen that DDT in bloater chub is higher. Fat content is also higher, but there are no consistent differences in content of other chlorinated compounds between these species, which however, came out higher than slimy sculpins.

Of the 5 samples for arsenic, at Mackinac Island and Goderich, both bloater chub had relatively higher values. Copper in slimy sculpin from Mackinac Island was higher than in the other fishes.

Differences in contaminants between locations

Alpena, Mackinac Island and Goderich show higher chlorinated compounds than Duck Island or Lonely Island. The difference does not seem to be related to size or fat content.

Legal requirements

PCB content is above the present Canadian limit of 2 $\mu\text{g/g}$ in bloater chub from Alpena and in burbot from Mackinac Island. All samples comply with U.S. and Canadian regulations for DDT and for mercury.

Radioactivity

Levels of radioactivity are all low and do not call for comment.

General

Since standard error is in most cases around $\pm 10\%$ of the means, the 95% confidence limits will be around $\pm 20\%$. The relatively small scatter of results may be ascribable to the sampling procedure which makes each analysis represent a composite of about 5 fish.

Qualitative organic analyses (Table 5) are nearly all confirmed by quantitative results where these exist. There is a discrepancy in indications for dieldrin. SSMS results are difficult to relate to analyses done by AAS. Zinc values are comparable. Low values for As and Se may be caused by volatilisation during ashing. High Co values may be due to contamination during grinding. Reasons for other discrepancies are not obvious.

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Table 1. Reproducibility of analyses ($\mu\text{g/g}$) Mean and SD($\pm$).

	n	Mean	SD ($\pm$)
PCB	4	3.93	0.29
Dieldrin	4	0.18	0.05
BHC	4	0.033	0.010
Chlordane	4	0.35	0.11
Total DDT	4	8.66	0.70
op' DDT	4	0.54	0.04
pp' DDT	4	2.35	0.21
op' DDE	4	0.035	0.003
pp' DDE	4	5.31	0.59
pp' DDD	4	0.49	0.03
Arsenic	24	10.6	1.4
	9	14.8	0.52
Cadmium	10	0.055	0.022
Chromium	10	0.06	0.011
Copper	10	0.70	0.05
Lead	10	0.046	0.006
Mercury	20	0.28	0.014
Selenium	10	0.51	0.02
Zinc	10	12.9	0.30

Table 2. LAKE HURON OFFSHORE FISH. Weight (g), length (mm), fat (%), PCB, pesticide residues and mercury (µg/g). Mean and SE (%).

	Duck Island				Georgian Bay, Lamely Island				Harbor Beach				Alpena			
	Bloater chub	Slimy sculpin	Burbot	Bloater chub	Slimy sculpin	Bloater chub	Slimy sculpin	Slimy sculpin	Slimy sculpin	Bloater chub	Bloater chub	Slimy sculpin	Bloater chub	Slimy sculpin	Bloater chub	Slimy sculpin
N	53	51	15	42	47	42	47	50	44	14	14	44	14	44	14	44
Weight	272	13.5	14.6	0.70	20	122	3.1	7.2	2	190	17.0	8.0	17.0	8.0	2	2
Length	204	5.1	93.7	1.73	36.7	5.6	2.2	76	2	251	6.6	80	6.6	80	2	2
n	10(3x6+7x5)	10(1x6+9x5)	10(5x1+5x2)	10(2x5+8x4)	10(7x5+3x4)	10(2x5+8x4)	10(7x5+3x4)	10(10x5)	10(4x5+6x4)	10(4x2+6x1)	10(4x2+6x1)	10(4x5+6x4)	10(4x2+6x1)	10(4x5+6x4)	10(4x2+6x1)	10(4x5+6x4)
Fat ¹	21	0.88	6	0.45	5	0.52	9	0.44	6	0.33	21	1.1	6	0.62	6	0.62
PCB	1.25	0.22	0.52	0.04	0.81	0.19	0.89	0.10	0.77	0.04	2.61	0.21	0.55	0.07	0.55	0.07
Dieldrin	0.18	0.01	0.14	0.01	0.07	0.008	0.08	0.008	0.11	0.006	0.20	0.02	0.14	0.02	0.14	0.02
Total DDT	1.46	0.06	0.60	0.03	1.04	0.35	2.17	0.21	0.76	0.05	4.37	0.45	0.65	0.10	0.65	0.10
op' DDT	0.16	0.02	0.10	0.009	0.08	0.02	0.16	0.01	0.06	0.005	0.40	0.04	0.07	0.01	0.07	0.01
pp' DDT	0.42	0.07	0.21	0.01	0.31	0.07	0.76	0.06	0.31	0.03	1.60	0.18	0.25	0.04	0.25	0.04
op' DDE	0.06	0.007	0.03	0.002	0.02	0.005	0.03	0.004	0.01	0.001	0.08	0.01	0.04	0.006	0.04	0.006
pp' DDE	0.70	0.07	0.20	0.01	0.52	0.22	1.11	0.12	0.34	0.02	2.05	0.25	0.22	0.04	0.22	0.04
pp' DDD	0.12	0.01	0.06	0.004	0.11	0.03	0.11	0.02	0.04	0.004	0.24	0.02	0.06	0.007	0.06	0.007
Mercury	0.05	0.003	0.06	0.004	0.11	0.008	0.17	0.008	0.12	0.004	0.10	0.004	0.08	0.006	0.08	0.006

¹ Hexane extractable matter

² Individual fish not measured

Table 3. LAKE HURON OFFSHORE FISH. Weight (g), length (mm), fat¹ (%) PCB and pesticide residues (µg/g). Mean and SE (±).

Mackinac Island				Goderich			
	Burbot	Bloater chub	Slimy sculpin	Burbot	Bloater chub		
N	50	29	72	52	50		
Weight	2436	125	230	467	20.2	281	10.9
Length	649	12.1	269	390	5.35	282	3.61
n	10(10x5)	10(9x3+1x2)	10 2x10+1x8 +3x7+3x6 +1x5	10(2x6+8x5)	10 (10x5)		
Fat ¹	7	0.35	22	5	0.15	20	0.66
PCB	2.35	0.31	1.68	0.77	0.05	1.48	0.12
Dieldrin	0.12	0.01	0.29	0.08	0.01	0.38	0.04
BHC	0.01	0.006	0.04	0.04	0.01	0.03	0.003
Methoxychlor	-2	-	-2	-2	-	-2	-
Chlordane	0.18	0.02	0.30	0.14	0.01	0.49	0.05
Total DDT	1.77	0.26	3.52	0.53	0.05	2.75	0.53
op' DDT	0.10	0.01	0.34	0.04	0.005	0.33	0.07
pp' DDT	0.52	0.08	1.18	0.16	0.02	0.86	0.22
op' DDE	0.01	0.002	0.07	0.03	0.005	0.28	0.04
pp' DDE	1.00	0.15	1.69	0.22	0.02	1.02	0.17
pp' DDD	0.15	0.02	0.24	0.08	0.01	0.26	0.03

¹ Hexane extractable matter

² Less than 0.05

Table 4. LAKE HURON OFFSHORE FISH. Metals ($\mu\text{g/g}$) Mean and SE ($\pm$) For weight, etc. see Table 2.

Mackinac Island				Goderich			
	Burbot	Bloater Chub	Slimy sculpin	Burbot	Bloater Chub		
n	10	10	10	10	10		
Arsenic	0.46 0.02	2.26 0.13	0.38 0.01	0.23 0.01	1.72 0.07		
Cadmium	0.015 0.001	0.040 0.004	- ₁	0.021 0.001	0.018 0.002		
Chromium	0.12 0.008	0.05 0.005	- ₁	0.07 0.004	0.02 0.002		
Copper	0.80 0.04	0.79 0.03	2.92 0.12	0.75 0.05	0.69 0.03		
Lead	0.041 0.002	0.10 0.01	- ₁	0.066 0.010	0.062 0.003		
Mercury	0.18 0.008	0.11 0.005	0.07 0.003	0.06 0.003	0.08 0.003		
Selenium	0.66 0.007	0.56 0.02	0.81 0.01	0.80 0.02	0.63 0.02		
Zinc	12.7 0.41	15.6 0.74	17.2 0.66	11.8 0.21	17.0 0.74		

1 Not determined

1 Not determined

Table 5. LAKE HURON OFFSHORE FISH. Detected (+) and not detected (-) organic compounds in burbot.

	Mackinac Island	Goderich
Biphenyl	-	+
Naphthalene and methyl naphthalenes	+	+
Phenanthrene and methyl phenanthrenes	+	+
Diethyl phthalate	+	+
Dibutyl phthalate	+	+
Di-2-ethyl hexylphthalate	+	+
Trichlorobenzene	+	+
Tetrachlorobenzene (2 isomers)	-	+
Pentachlorobenzene	-	+
Hexachlorobenzene	+	+
Octachlorobiphenyl (3 isomers)	+	+
Octachlorostyrene	-	+
1,2,3,4,5,6, Hexachloro cyclohexane (alpha)	-	-
" (gamma)	-	-
Heptachlorepoxyde	+	-
Chlordane (cis- and trans-)	+	+
Nonachlor (cis- and trans-)	+	+
Oxychlordane	+	-
Dieldrin	-	-
pp' DDT	+	+
op' DDE	+	-
pp' DDE	+	+
pp' DDD	+	+
pp' DDMV	-	-
Toxaphene components (C ₁₀ H ₈ Cl _{7,8} , trans-)	+	-
Methyl benzothiophene	-	+

Table 6. LAKE HURON OFFSHORE FISH. Analysis by spark source mass spectrometry ($\mu\text{g/g}$).

	Goderich	
	Burbot	Bloater Chub
Pb	0.095	0.075
Nd	-	-
Pr	-	0.020
Ce	-	-
La	0.025	0.060
Ba	0.25	0.030
Cs	-	-
I	18	12
Te	0.050	-
Sn	0.82	0.35
In	0.025	0.055
Cd	-	0.170
Ag	0.060	0.080
Rh	-	-
Mo	0.030	-
Sr	3.2	3.8
Rb	2.4	2.2
Br	8.5	5.3
Se	0.19	0.28
As	0.005	0.013
Ge	0.16	1.3
Ga	0.02	0.12
Zn	16	25
Co	0.24	1.0
Fe	22	11
Mn	1.7	2.4
Cr	0.68	1.8
V	0.075	0.26
Ti	0.13	0.16
Sc	0.075	0.44
F	0.83	0.27

Table 7. LAKE HURON OFFSHORE FISH Radioactivity

Total beta activity as ^{40}K equivalent (pCi/g wet weight)Gamma activity as ^{137}Cs (pCi/g wet weight) Mean and S.E. ($\pm$)

	Mackinac Island		Goderich	
	Burbot		Burbot	
N	50		52	
n	10		10	
Total beta	1.90	0.03	2.02	0.03
Gamma	0.167	0.009	0.085	0.003

SAMPLING STATIONS
MS Mockinac Island
A Alpena
HB Harbour Beach
G Gederich
LI Lonely Island
DI Duck Island

Fig. 1. Lake Huron and sampling locations

MILES
0 10 20 30 40
0 20 40 60
KILOMETRES

POOR

QUALITY

ORIGINAL